BioSpace25 - Biodiversity insight from Space
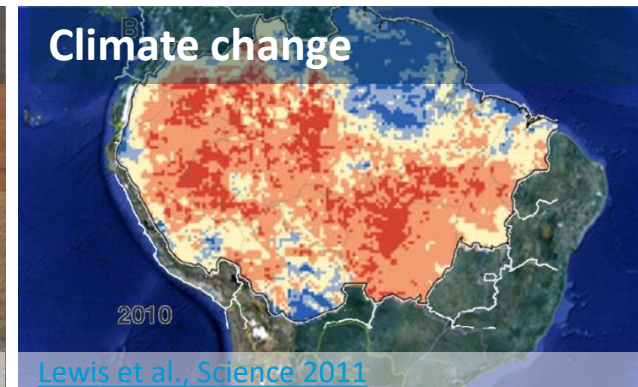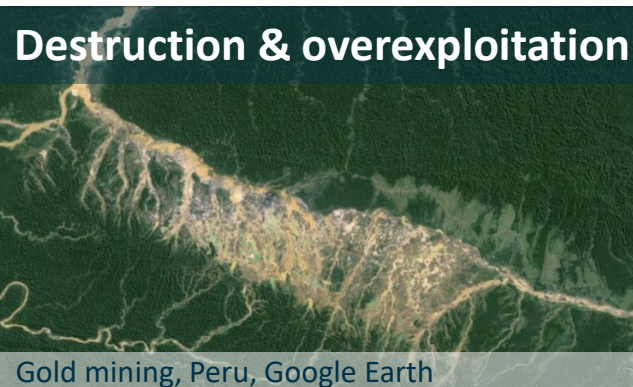10 - 14 February 2025 | ESA-ESRIN | Frascati - Italy

An EO-based framework for monitoring tropical forests ecosystems in Costa Rica: extent, condition and composition

J.-B. Féret, F. de Boissieu, R. Cresson, M. Bonnier, M. Souza Oliveira, S. Alleaume, S. Luque

1

Mapping and monitoring biodiversity & ecosystem extent with satellites

- Biodiversity crisis particularly severe for tropical forested ecosystems

- Need for operational methods to monitor ecosystem dynamics through space and time

- Earth Observation Satellites provide key information for such monitoring, but operational applications need to :

  - Handle massive amounts of EO data

  - Use scalable methods able to extract ecologically relevant information

  - Efficiently combine and compare in situ observations and EO products

Destruction & overexploitation

Gold mining, Peru, Google Earth

Pests & invasive species

Simon Fraser University (pine beetle)

Land use change

http://green.blogs.nytimes.com

Climate change

Lewis et al., Science 2011

Mapping and monitoring biodiversity & ecosystem extent with satellites

Ecosystem Extent Task Team (EETT) from the **Committee on Earth Observation Satellites (CEOS)**

→ **How to use Earth observation data to support the critical Biodiversity variables of Ecosystem Extent ?**

We introduce a demonstrator dedicated to **Costa Rican forest mapping (INRAE / CNES, Luque et al.)**

- **Costa Rica is a biodiversity hotspot: 0.03 % of Earth's land surface** and ~**5% of the world's biodiversity**
- Strong topographic and climatic gradients: Presence of **tropical dry** and **tropical wet biomes**.
- **52% forested land area**: 36% secondary forests, 25% protected national parks, reserves & wildlife refuges [2]
- Ecological transition from **Pioneer in deforestation** (70s-80s) to **Leader in reforestation** (2000s) [1]
- Expertise and ground information : SINAC & CATIE

We provide perspectives and current limitations for application to larger scale

[1] Redo et al., 2012. https://doi.org/10.1073/pnas.1201664109   [2] Stan & Sanchez Azofeifa, 2019. https://doi.org/10.1007/s10113-018-1432-5

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Mapping Costa Rican forests with Sentinel-2 imagery

- **Objectives of the CEOS demonstrator**
  - Map biodiversity & floristic composition turnover over Costa Rican forest ecosystems with EO (Sentinel-2)
  - Assess conservation potential of secondary forests in human-modified landscapes
  - Compare conservation potential of intact and disturbed forests

- **Challenges for operational ecosystem extent & biodiversity mapping**
  - Free & open data / software / products infrastructure: reproducibility, benchmark analyses, product validation
  - Capacity to handle EO time series: cloud infrastructure & cloud native applications
  - Prepare for multi-sensor integration & future satellite missions (CHIME, SBG…)
  - Save time and money for public data providers, method developers and users

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Cloud infrastructures supporting research and operational biodiversity monitoring

- **Infrastructure developed in the frame of DATA TERRA, based on**
  - Fully open source solutions
  - Open standards (OGC): STAC / COG
  - Cloud-native architecture (S3 object storage)
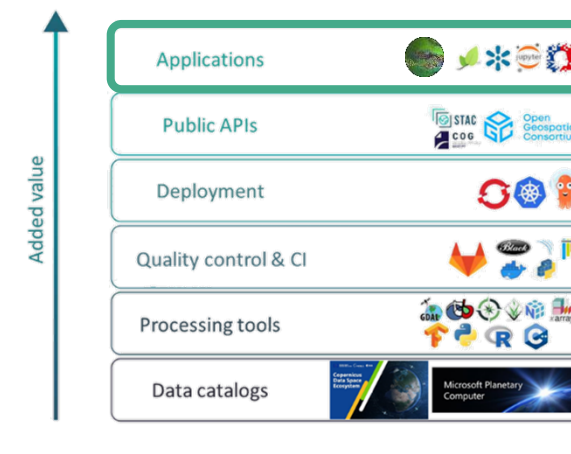 - Interoperability between providers : CDSE, MPC …

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- **Scalable forest properties mapping algorithms using EO data**
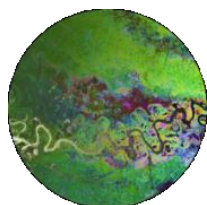
biodivMapR, an R package for α- and β-diversity mapping using remotely-sensed images
https://jbferet.github.io/biodivMapR/index.html

FORDEAD, a python package to monitor FORest DEcline And Dieback
https://fordead.gitlab.io/fordead_package/
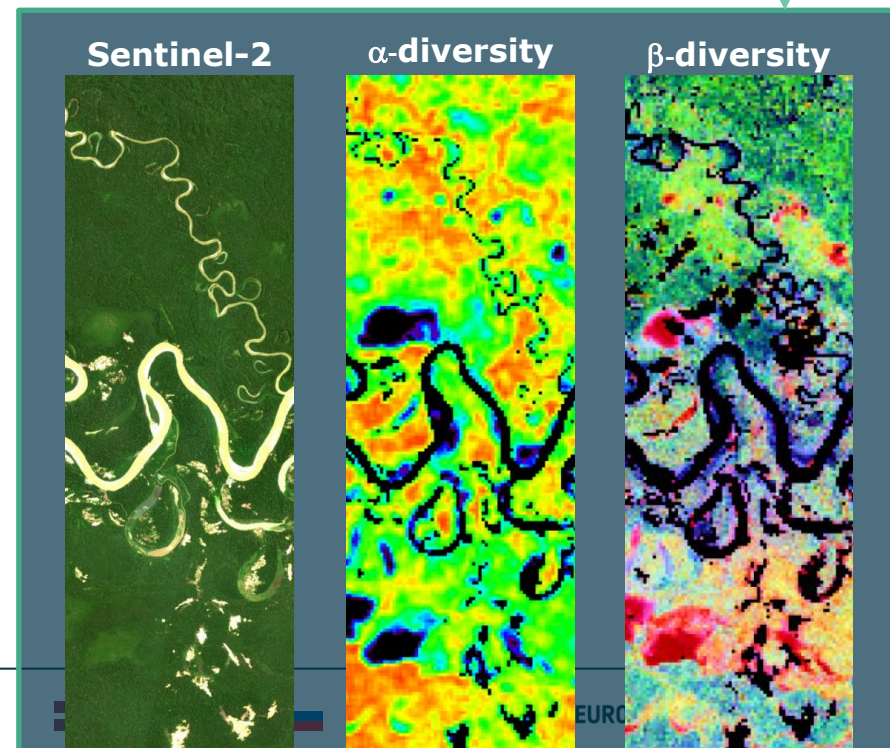
Sentinel-2   α-diversity   β-diversity

Cloud infrastructures supporting research and operational biodiversity monitoring

- Infrastructure is online, test phase & addition of new products:
  - Cloud-free SI syntheses from time series & describing key vegetation traits
  - Spectral diversity maps
  - …

- STAC / COG catalogs

- Allows product upload / download

- Software Development Kit available

- Accessible on QGIS via STAC API plugin

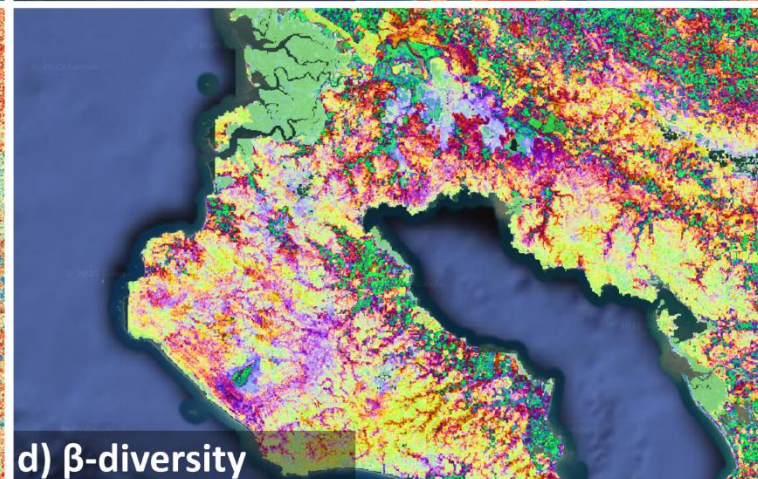# Application of biodivMapR to map forest diversity over Costa Rica

- Cloud free spectral index syntheses were produced from seasonal time series
- Yearly α- and β-diversity maps of Costa Rican forested ecosystems were produced with biodivMapR
- ⚠ Validation for floristic composition gradients, Ecosystem extent & conservation potential of ecosystems
- Interpretation of β-diversity maps :
    - dissimilarity in colors = spectral dissimilarity ~ dissimilarity in floristic composition

a) RBG imagery

b) Forest type
- Old-Growth Forest
- Secondary Forest
- Old-Growth Deciduous Forest
- Secondary deciduous forest
- Palm forest
- Mangrove

c) α-diversity

d) β-diversity

Shannon − +

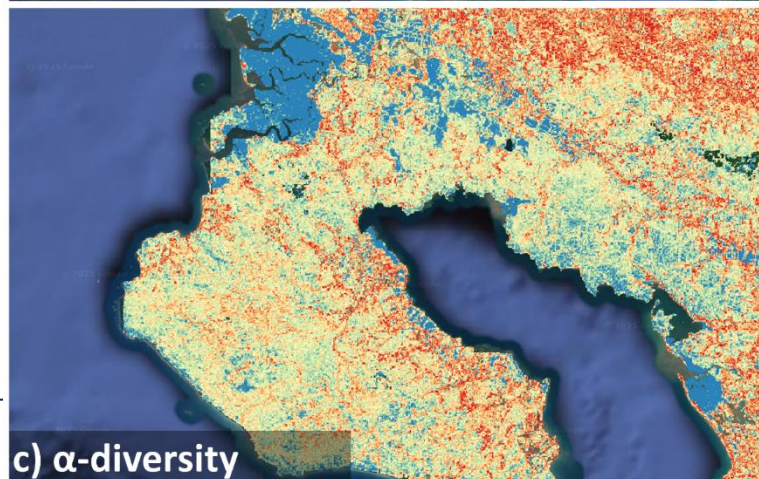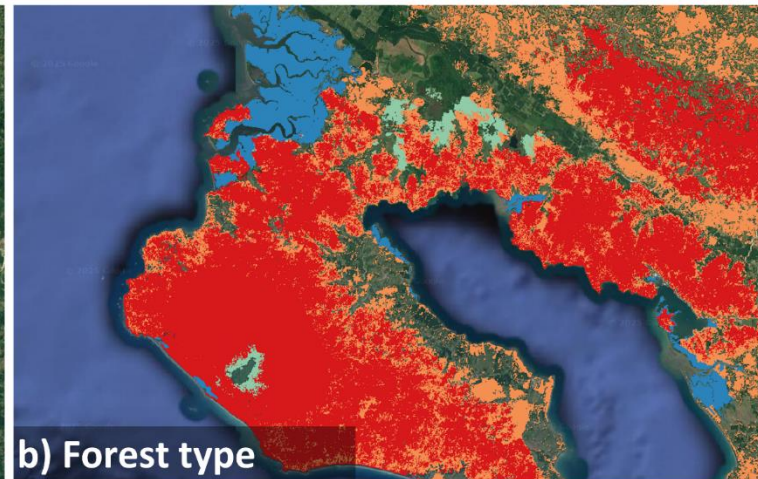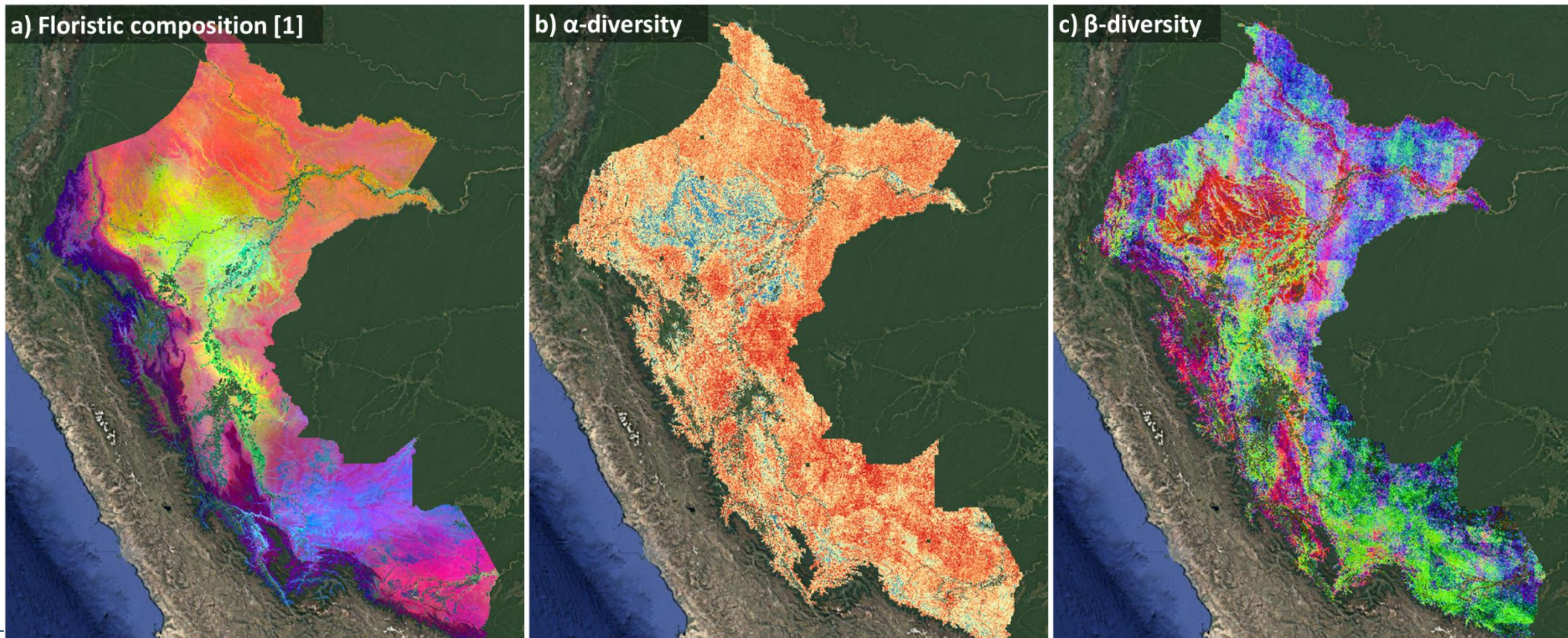# Application of biodivMapR to map forest diversity over Costa Rica

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a) RBG imagery
b) Forest type
c) α-diversity
d) β-diversity

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Application of biodivMapR to map forest diversity over Peruvian Forest

- Yearly α- and β-diversity maps produced with biodivMapR over forested ecosystems in Peruvian Amazon
  - Strong artifacts caused by lack of harmonization of Sentinel-2 data at country scale

a) Floristic composition [1]   b) α-diversity   c) β-diversity

[1] Chaves et al., 2020. https://www.mdpi.com/2072-4292/12/9/1523

Application of biodivMapR to map forest diversity over Peruvian Forest
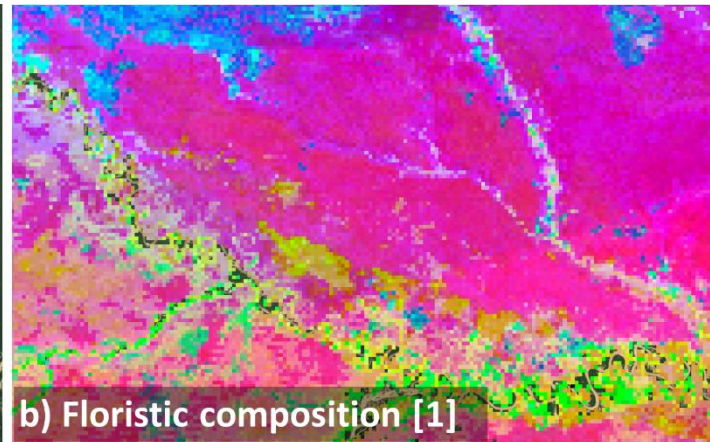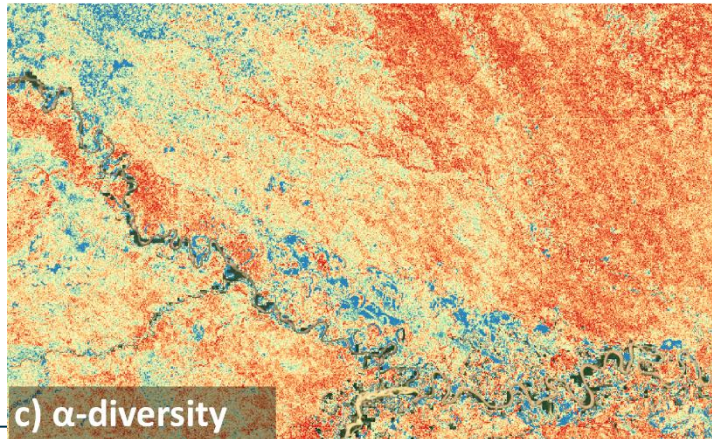
- Yearly α- and β-diversity maps produced with biodivMapR over forested ecosystems in Peruvian Amazon
  - Strong artifacts caused by lack of harmonization of Sentinel-2 data at country scale
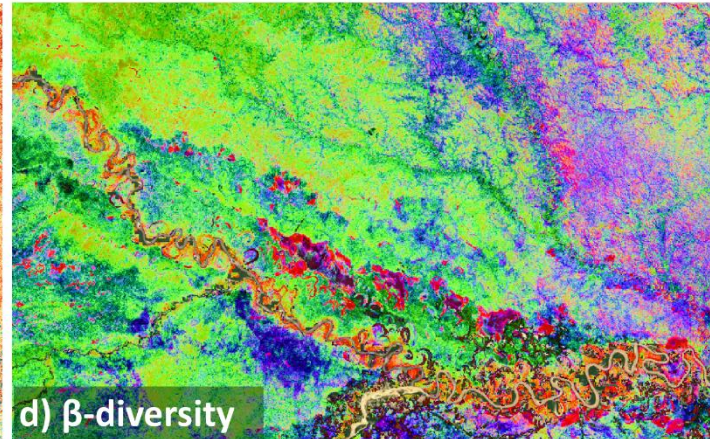 - Partial agreement with maps of floristic composition at local scale

a) RBG imagery

b) Floristic composition [1]

Chaves et al. 2020:
Floristic composition (450 m spatial resolution) :
- Landsat composites 2000-2009
- climatic, edaphic & elevation data
- Ground information
- Supervised machine learning (RF)

c) α-diversity

d) β-diversity

α / β diversity maps – Shannon's H & Floristic composition – (100 m spatial resolution) :
- S2 spectral indices synthesis 2014
- Application of biodivMapR

[1] Chaves et al., 2020. https://www.mdpi.com/2072-4292/12/9/1523

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Application of biodivMapR to map forest diversity over French Guiana

- Yearly α- and β-diversity maps produced with biodivMapR over forested ecosystems in French Guiana
  - Strong artifacts caused by lack of harmonization of Sentinel-2 data at territory scale

a) Forest habitat types b) α-diversity c) β-diversity

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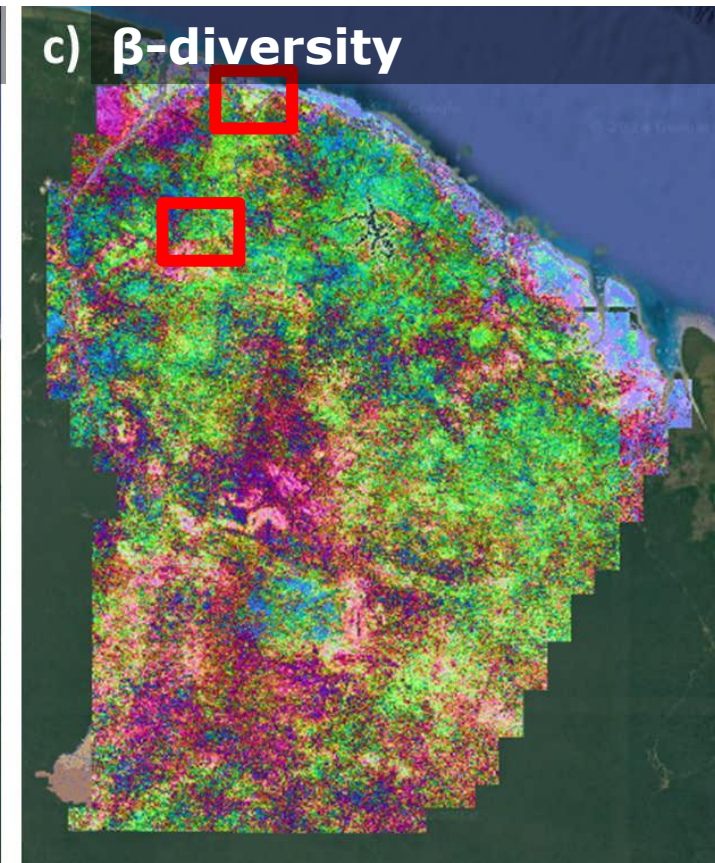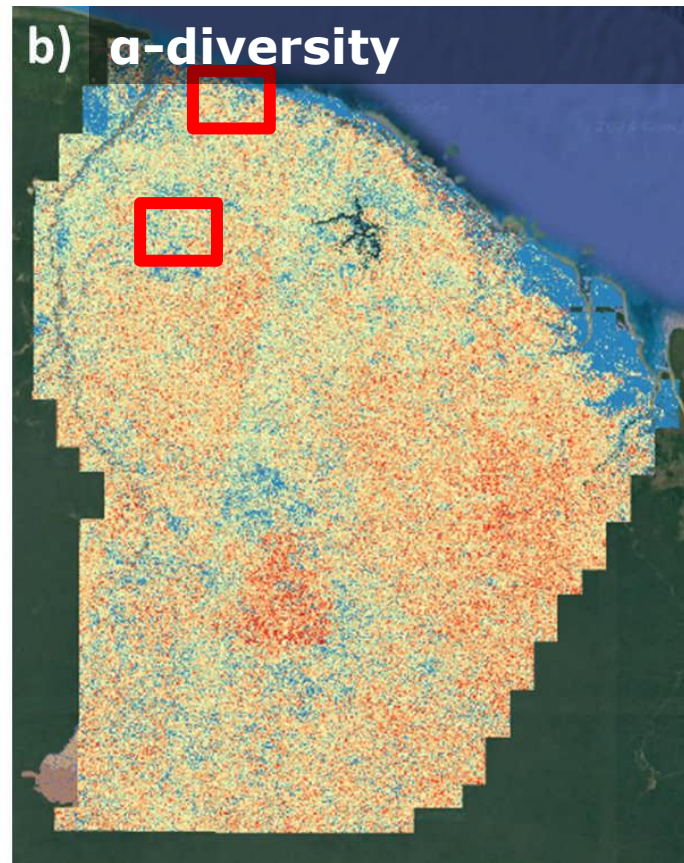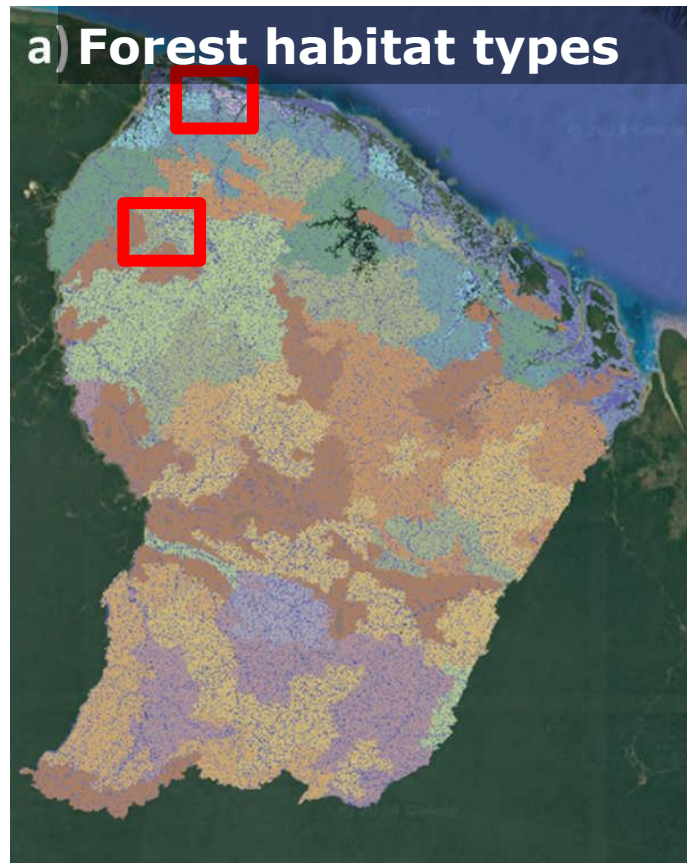
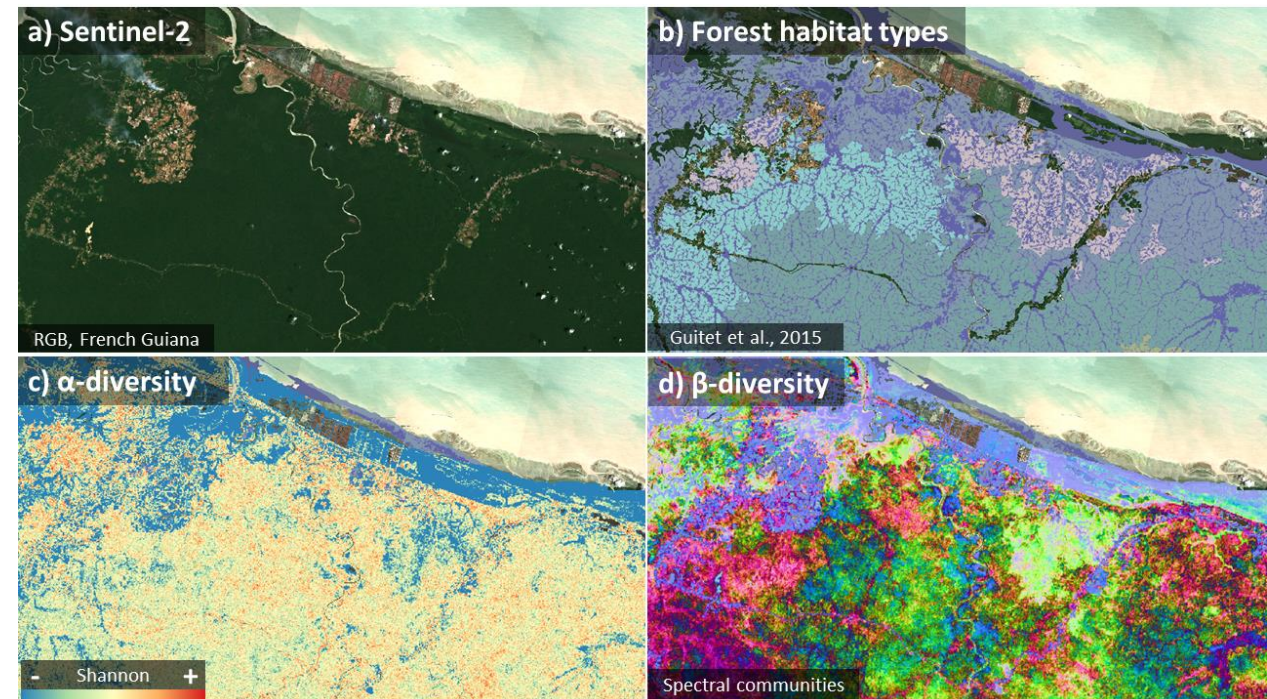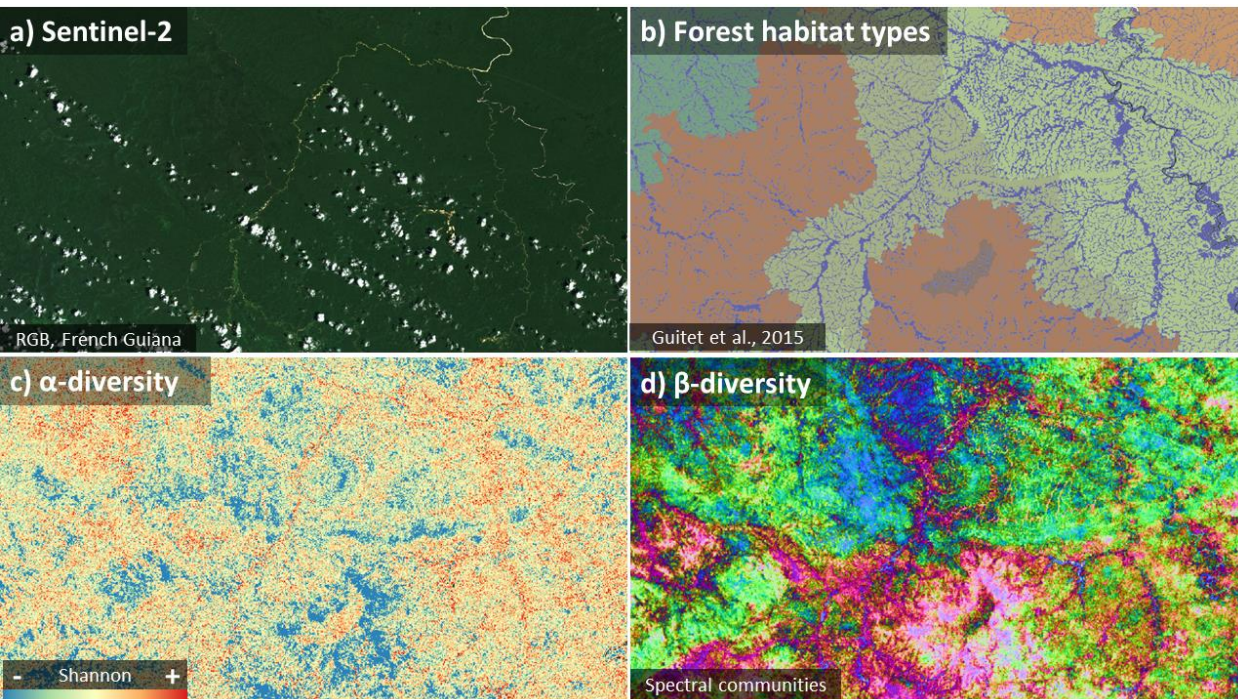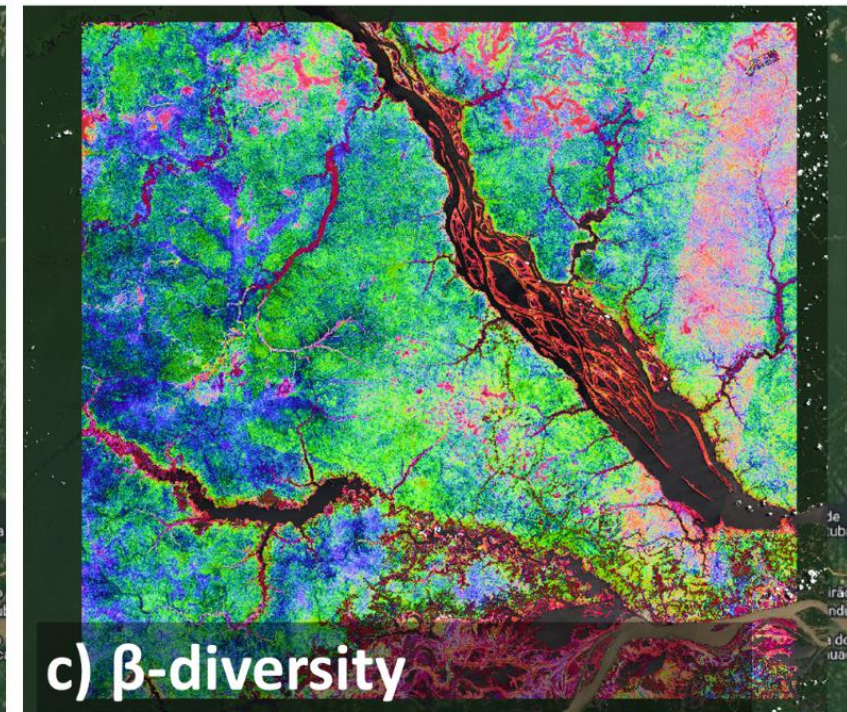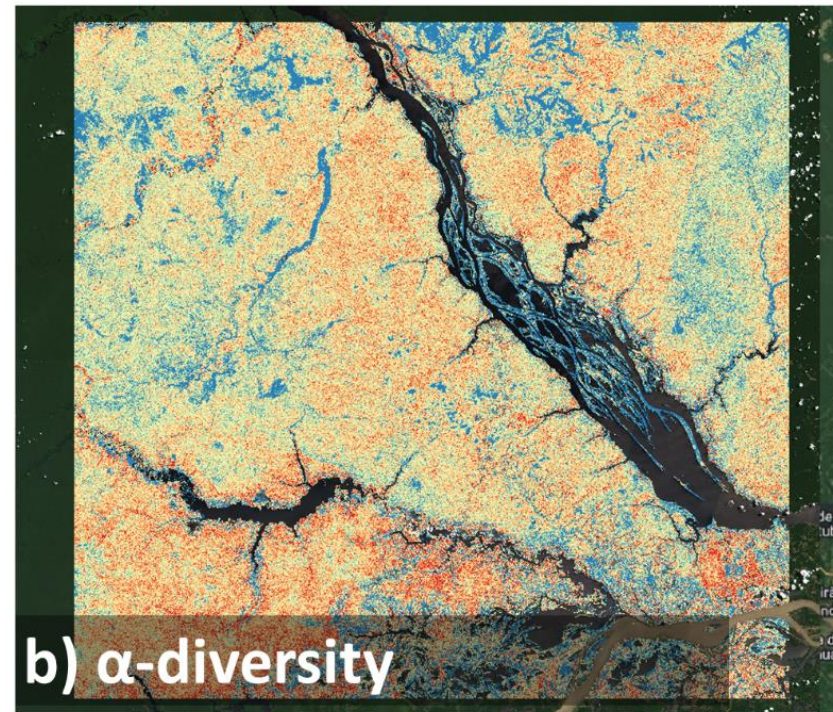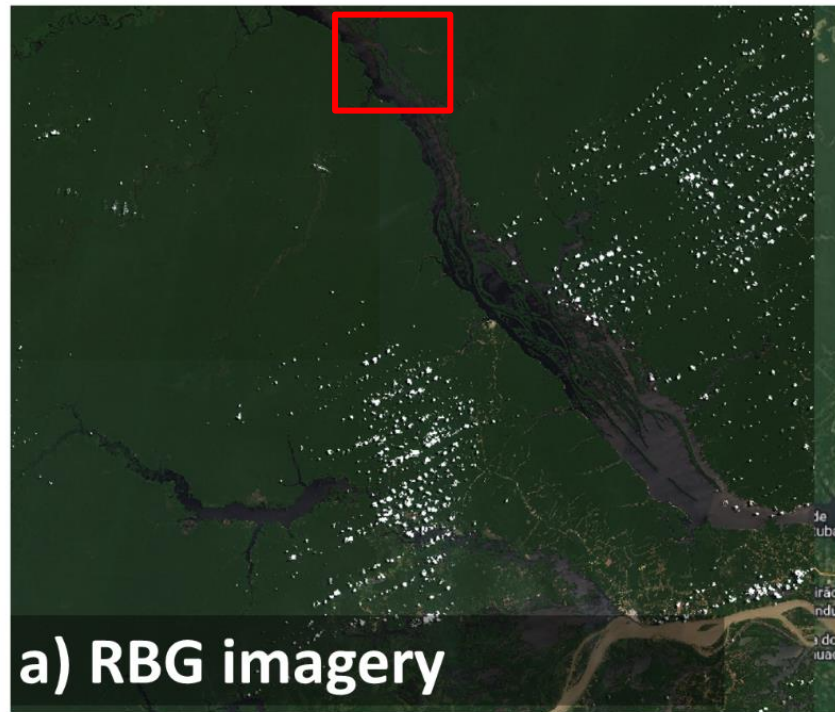# Application of biodivMapR to map forest diversity over French Guiana

- Yearly α- and β-diversity maps produced with biodivMapR over forested ecosystems in French Guiana
  - Strong artifacts caused by lack of harmonization of Sentinel-2 data at territory scale
  - Partial agreement with forest habitat maps at local scale
  - ⚠ validation with forest inventory plot network

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Application of biodivMapR to map forest diversity over Brasilian Forest

- Yearly α- and β-diversity maps produced with biodivMapR over Rio Negro, Brasil
- Specific focus on site near Manaus mentioned by Musonda Mumba (opening session)
- ⚠️ Exchange with wetland experts community to identify potential of such spatial information

a) RBG imagery
b) α-diversity
c) β-diversity

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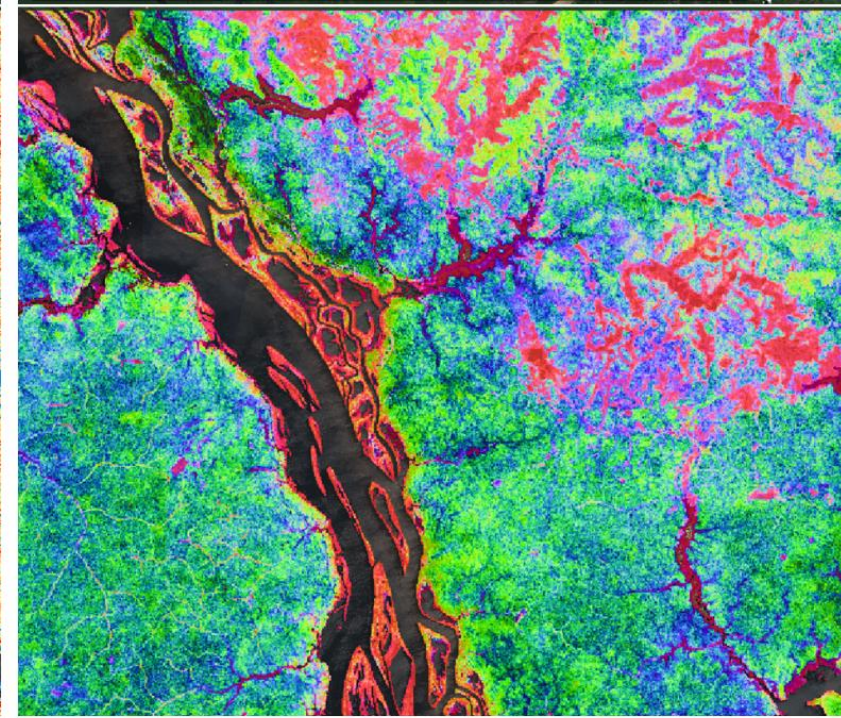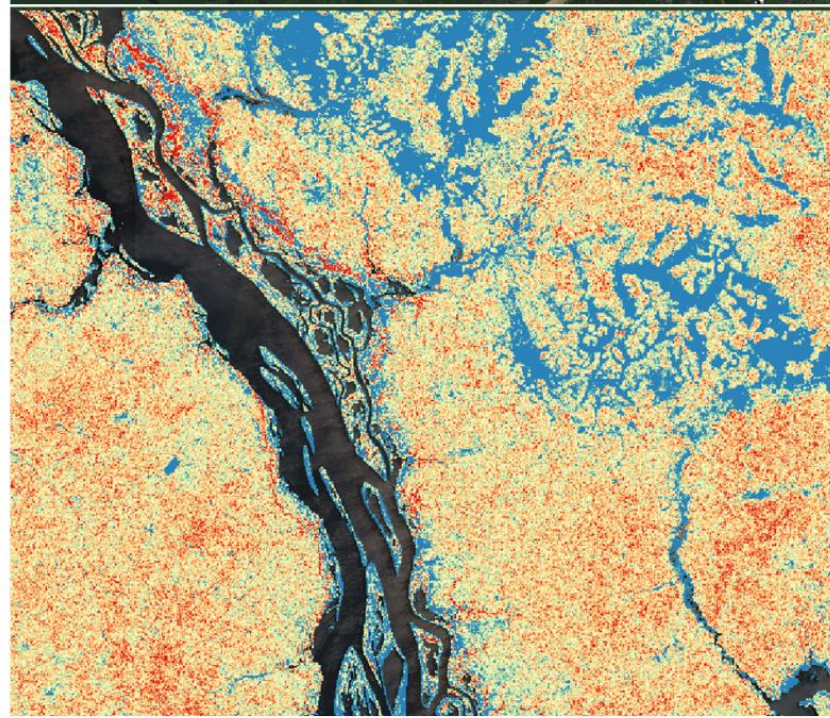# Application of biodivMapR to map forest diversity over Brasilian Forest

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Conclusions & perspectives

- A **cloud infrastructure** hosting data, processing tools and user level products has been developed

- Foundation for a **CEOS demonstrator** to map floristic composition in tropical forests over **Costa Rica**
  → Production of large scale spectral diversity maps related to biodiversity and floristic composition

- Preliminary expansion to other regions, including French Guiana, Peru and other tropical territories

- Capacity to **process massive datasets** : Sentinel-2 time series, multi-sensor analysis at country scale …

- Need to **anticipate data standards for future satellite missions for easier integration & interoperability**
  → CHIME, SBG, LSTM, …

- **Key recommandations:**
  - **Free & open data / software / products infrastructure for reproducibility, product validation, benchmark analyses & intercomparisons**
  - **Promote interoperability between EO & biodiversity data hubs (e.g. GBIF, BON in a BOX), combined with documented demonstrators to improve connections between RS & ecology communities**
  - **Improve data harmonization for large scale tropical forest diversity mapping (e.g. BRDF, atmosphere)**

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Thank you !

jb.feret@teledetection.fr